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BIOMECHANICS

Competing Effects of Pain and Fear of Pain on Postural Control in Low Back Pain?

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Study Design. A cross-sectional, observational study.

Objective. To determine whether pain and fear of pain have competing effects on postural sway in patients with low back pain (LBP).

Summary of Background Data. Competing effects of pain and pain-related fear on postural control can be proposed as the likely explanation for inconsistent results regarding postural sway in the LBP literature. We hypothesized that although pain might increase postural sway, fear of pain might reduce sway through an increased cognitive effort or increased cocontraction to restrict body movement. The cognitive strategy would be less effective under dual-task conditions and the cocontraction strategy was expected to be less effective when standing on a narrow base of support surface.

Methods. Postural sway was measured in combined conditions of base of support (full and narrow) and cognitive loading (single and dual tasks) in 3 experimental groups with current LBP, recent LBP, and no LBP. Sway amplitude, path length, mean power frequency, and sample entropy were extracted from center-of-pressure data.

Results. The current-LBP group and recent-LBP group reported significantly different levels of pain, but similar levels of pain catastrophizing and kinesiophobia. The current-LBP group tended to display larger sway amplitudes in the anteroposterior direction compared with the other 2 groups. Mean power frequency values in mediolateral direction were lower in patients with the current LBP compared with recent LBP. Smaller sample entropy was found in the current-LBP group than the other groups in most experimental conditions, particularly when standing on a narrow base of support.

Conclusion. Alterations of postural sway are mostly mediated by pain but not pain-related fear. LBP tends to increase sway amplitude, which seems to be counteracted by increased effort invested in postural control leading to decreased frequency and increased regularity of sway particularly under increased task demands.

Key words: low back pain, quiet standing, center of pressure, postural sway regularity, pain, fear of pain, attention, dual task, support surface, nonlinear analysis.

Level of Evidence: Cross-sectional study

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Numerous studies have investigated postural control in patients with low back pain (LBP). In a recent review, Ruhe *et al*[1] concluded that the majority of studies show an increased postural sway amplitude and/or velocity in bipedal stance in patients with nonspecific LBP. However, a more extensive analysis demonstrated that the literature is not as consistent as suggested.[2] For example, Mok *et al*[3] and Salavati *et al*[4] even reported decreased sway in patients with LBP compared with healthy subjects. In these 2 studies, patients were tested during a relatively pain-free period, whereas in the majority of studies with increased sway in LBP, patients experienced high levels of pain.

Pain can disrupt the sensorimotor processes underlying postural control, leading to increased sway.[5] A decrease in force steadiness has been shown to occur with experimentally induced LBP[6] as well as with clinical LBP,[7] and might be a cause of increased sway. In addition, nociceptive afferents have negative effects on proprioceptive feedback,[8] which may also contribute to increased sway.

Postural control impairments persist in patients with LBP even when they currently experience no pain.[9,10] The presence of these changes in the absence of an active pain episode may be the result of fear of pain (FoP). On the basis of the fear-avoidance model, interpretation of pain as catastrophic may give rise to FoP and avoidance of activities that are assumed to increase pain or cause reinjury.[11] This may have an impact on posture leading to more rigid control, reflected by a decreased sway with a relatively high-frequency content. This would be in line with the low sway amplitudes in patients with a history of LBP but low levels of pain or no pain at the time of testing.[3,4,12] Although there is lack of evidence regarding the direct effect of FoP on postural control, authors have reported reduced postural sway when standing on an elevated surface,[13] or when viewing aversive affective pictures.[14]

Postural control changes with LBP may play a role in persistence and recurrence of symptoms. However, to date, the exact cause of altered postural control in patients with LBP is still unclear. Understanding potential roles of pain and FoP, which is the main focus of this study can aid clinicians to target the appropriate causative factor for changes in postural control. To study effects of pain and FoP, we recruited participants with LBP and participants who had recently recovered from LBP. In the latter group, we expected that FoP would still be present, whereas pain and hence direct effects of pain would be minimal. The effect of pain was thus assessed by comparing postural variables between the current-LBP group *versus* recent-LBP group and no-LBP group. The effect of FoP was assessed by comparing postural variables between the current-LBP group and recent-LBP group *versus* no-LBP group.

We hypothesized larger sway in patients with current LBP (compared with the control group and recent-LBP group) and lower sway with a higher frequency content in participants with recent LBP (compared with the control group and current-LBP group).

The more rigid postural control that we suggest to be a result of FoP may be achieved through increasing levels of cocontraction, which would reduce sway amplitudes when standing on a rigid, full base of support (BOS), but was suggested to be ineffective when standing on a narrow BOS.[3] Thus, we hypothesized that sway amplitudes would increase when standing on a narrow beam and more so in participants with FoP.

FoP might alternatively impose its effect on postural sway through an increased cognitive effort to restrict body movement. We, therefore, hypothesized that increased cognitive loading (COG) would increase sway by distracting from postural control, particularly in fearful patients with LBP. Sample entropy (SEn) as a measure that quantifies regularity of postural sway and hence cognitive effort invested in postural control[15] was therefore assessed. Smaller SEn values reflect more regular center of pressure (COP) fluctuations and are associated with increased attentional investment in postural control.

MATERIALS AND METHODS

Participants

Data were collected from 3 groups of volunteers with current LBP, a recent history of LBP, and no LBP, each composed of 20 participants. Participants in both current-LBP group and recent-LBP group were diagnosed with nonspecific LBP based on negative results on a number of "red flag" questions that indicate risk factors for serious spinal pathology. Nerve-root irritation was also excluded on the basis of absence of findings of pain radiating below buttock and a negative straight leg raising test. Participants were included in the current LBP-group, if they had current, nonspecific LBP for at least 6 weeks, a pain score of 3 or more on a visual analogue scale, and pain during quiet standing. They were recruited from new patients referred to physical therapy clinics. Participants with recent LBP had to have previous nonspecific LBP episodes of at least 6 weeks duration during the past year and a current pain score less than 3 on visual analogue scale. These participants were recruited from patients who had been referred to physical therapy clinics due to LBP during the past year. Participants in the no-LBP group had to have no history of LBP or other musculoskeletal disorders related to the low back in the previous 12 months. These participants were recruited from students and staff of the university. Participants in all 3 groups were excluded if they had uncorrected visual impairment, auditory and cognitive disorders, cardiovascular or respiratory disorders, vestibular or neurological disorders, diabetes, pregnancy, or use of medicine affecting postural control, and a history of spinal surgery. All participants signed an informed consent form approved by the local ethics committee.

Measurements

Questionnaires

All participants were asked to complete the Baecke Physical Activity Questionnaire.[16] In addition, the participants in the current-LBP group and recent-LBP group were asked to complete the Oswestry Disability Index,[17] the Tampa Scale for Kinesiophobia,[18] and the pain catastrophizing scale.[19] Pain intensity was also quantified using a visual analogue scale, with 2 anchors of 0 and 100 representing "no pain" and "worst pain imaginable," respectively.

Force Platform

A portable Kistler force platform (500 × 600 mm, type 9260 AA; Kistler Instruments, Winterthur, Switzerland) was used to collect COP data along x-axis and y-axis representing anteroposterior (AP) and mediolateral (ML) directions, respectively. Data were sampled at a rate of 100 samples/second producing a total of 6000 COP data points for a recording of 60 seconds.

Procedure

The questionnaires and demographic data form were administered before data collection. For the preparation trial, participants were familiarized with the standing on a narrow BOS and COG for a short period, until they fully understood the task.

Each participant was exposed to 4 different combined conditions of BOS (wide and narrow) and COG (single and dual task) that were randomly presented. Each condition consisted of 3 trials. Each trial lasted 60 seconds with a rest period of 60 seconds between trials.

In all trials, participants stood barefoot on the force platform with hands hanging at the sides and the feet separated at shoulder width. To standardize foot position across trials, foot placement was traced on a piece of paper overlaying the force platform.

Two different configurations of BOS, differentiating in AP dimensions were used during standing. In half of the trials, participants stood on the force platform, whereas in the remaining trials, they stood on a block, measuring 9 cm in the AP direction, placed on the platform underneath the malleoli[3] (Figure 1).

Figure 1. Experimental setup. Standing on a wooden block (9-cm wide in anteroposterior direction) placed on the force platform underneath the malleoli and facing the screen that displays digits printed in different colors.

In single-task condition, participants stood relaxed while looking at a screen at a distance of 3.60 m in front of them. In the dual-task condition, the participants were asked to perform a mental tracking task that is to count the number of digits printed in a specified color among a series of digits printed in different colors. PowerPoint slides (Microsoft Office, 2010; Microsoft Corporation, Redmond, WA) were used to display the digits on a screen at the distance of 3.60 m at the subjects' eye level. To avoid the disturbing effect of articulation on body sway, the participants were asked not to speak during the task but to report the result after the trial. To detect the effect of the balance task on cognitive performance, the participants were requested to do the mental task in the sitting position as well.

Data Analysis

Before calculating postural parameters, the first 5 seconds of each trial were discarded. The sway amplitude was expressed by the standard deviation of COP positions in AP direction and standard deviation of COP positions in ML direction, and sway speed was expressed by the path length. The frequency content of the time series was determined by the mean power frequency (MPF) in AP direction and MPF in ML direction. The regularity of postural sway was quantified using SEn.

To detect performance on the secondary cognitive task, the number of errors and correct responses during 1-minute collection were recorded.

Statistical Analysis

The average of 3 recordings of postural variables was used for further analysis. One-way analysis of variance (ANOVA) was used to compare demographic variables between the 3 groups. Differences in pain intensity, disability level, fear-avoidance beliefs and pain catastrophizing between the 2 groups of LBP were tested with independent *t* tests. Postural performance was analyzed using separate 3 (group) by 2 (BOS) by 2 (COG) mixed-model ANOVAs. α was set at 0.05 for each analysis. One-way ANOVA was used for simple main-effect analysis and Bonferroni corrections were made for multiple comparisons.

The number of errors made in the COG was compared between sitting, standing, and standing on the narrow BOS and between groups using mixed-model ANOVA.

RESULTS

There were no significant differences in age, height, weight, and physical activity level between the 3 groups. The patients with current LBP reported significantly more pain and disability than the recent-LBP group, but between-group differences were not significant for pain catastrophizing scale and Tampa Scale for Kinesiophobia scores (Table 1).

Table 2 summarizes the results of the ANOVAs. The current-LBP group tended to display larger standard deviation of COP positions in AP direction values than the other 2 groups (Figure 2A). A significant group effect was found for MPF in ML direction with lower values in patients with

TABLE 1. Characteristics of Participants With a Recent History of LBP, Current LBP, and no LBP

	Current LBP (n = 20)	Recent LBP (n = 20)	No LBP (n = 20)	*P*
Age (yr)	33.5 ± 9.2	35.3 ± 10.2	34.3 ± 7.6	0.83
Height (cm)	168.3 ± 10.1	167.4 ± 13.6	165.1 ± 8.7	0.65
Weight (kg)	67.4 ± 11.7	68.9 ± 12.5	67.7 ± 9.7	0.91
Sex (female/male)	12/8	12/8	12/8	
Physical activity	7.2 ± 1.3	7.3 ± 1.3	7.3 ± 1.3	0.95
TSK (scale, 17–68)	43.6 ± 7.7	41 ± 6.7	N/A	0.25
PCS (scale, 0–52)	23.4 ± 11.9	16.8 ± 11.9	N/A	0.09
ODI (scale, 0–50)	16.1/50 ± 8.3	9.5/50 ± 5	N/A	**<0.001**
VAS (mm)	50.9 ± 21.2	11.5 ± 9.5	N/A	**<0.001**

TSK indicates Tampa Scale for Kinesiophobia; PCS, pain catastrophizing scale; ODI, Oswestry Disability Index; VAS, visual analogue scale.
Significant values are highlighted with boldface.

TABLE 2. Main and Interaction Effects of LBP History, Base of Support, and Cognitive Loading on Different Parameters of Postural Sway

	SD_x		SD_y		PL		MPF_x		MPF_y		SE	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Main effects												
Group	3.03	0.06	2.27	0.11	0.004	1.00	1.91	0.16	3.24	**<0.05**	3.86	**<0.05**
BOS	109.45	**<0.001**	231.68	**<0.001**	630.72	**<0.001**	306.38	**<0.001**	87.33	**<0.001**	120.10	**<0.001**
COG	0.02	0.89	10.48	**<0.01**	7.22	**<0.01**	0.04	0.84	0.07	0.79	0.85	0.36
Interactions												
Group × BOS	1.60	0.21	0.25	0.78	1.03	0.36	1.94	0.15	1.20	0.31	1.13	0.33
Group × COG	0.43	0.66	0.94	0.40	0.24	0.79	0.46	0.63	1.46	0.24	0.77	0.47
BOS × COG	1.51	0.22	1.21	0.28	8.27	**<0.01**	0.34	0.57	0.03	0.87	1.19	0.28
Group × BOS × COG	0.79	0.46	1.00	0.38	0.04	0.96	2.13	0.13	0.13	0.88	3.72	**<0.05**

LBP indicates low back pain; SD_x, standard deviation in AP direction; SD_y, standard deviation in ML direction; PL, path length; MPF_x, mean power frequency in AP direction; MPF_y, mean power frequency in ML direction; SE, sample entropy; BOS, base of support; COG, cognitive loading.

Significant values are highlighted with boldface.

current LBP compared with the recent-LBP group (Figure 2E). However, no group effects on standard deviation of COP positions in ML direction and path length and MPF in AP direction were found (Figure 2B–D), nor were there any significant interactions with group. An interaction of group with BOS and COG was found for SEn. The current-LBP group displayed lower SEn values than the other groups in all conditions with the exception of standing on the full BOS while performing COG. The difference was significant compared with the recent-LBP group (in the full BOS, single-task condition) and the no-LBP group (in the narrow BOS, dual-task condition). The group effect was marginally significant in the narrow BOS, single-task condition ($P = 0.07$) (Figure 2F).

Sway amplitude increased when standing on the narrow beam compared with full BOS. With narrow BOS also sway frequency increased compared with full BOS. Standard deviation of COP positions in ML direction increased from the control to the dual-task condition. The interaction of COG with BOS for path length indicated increased sway speed from control to dual-task condition while standing on narrow BOS. The number of cognitive errors was not higher than in sitting and not affected by BOS (sitting: 15; full BOS: 14; narrow BOS: 18), nor was it different between groups (current LBP: 12; recent LBP: 17; no LBP: 18).

DISCUSSION

As expected, patients with current LBP tended to display larger sway compared with other groups. MPF was lower in the current-LBP group than in the recent-LBP group. In addition, these patients showed more regular sway than other groups in most experimental conditions, particularly when standing on narrow BOS. Sway did not have lower amplitudes in patients with recent LBP than in controls, in contrast with our hypotheses. Sway amplitude increased when standing on a narrow instead of full BOS, but this difference was not larger for patients with recent LBP.

In contrast to our initial hypothesis based on competing effects of pain and FoP, the results showed no or minimal effect of FoP on postural sway, whereas changes found seem to be mediated by the presence of pain. This is deduced from the observations of no change in postural sway in the recent-LBP group (with FoP) and of significant alterations in the current-LBP group (with both pain and FoP). These results suggest that FoP, as assessed by the pain catastrophizing scale and Tampa Scale for Kinesiophobia, is not sufficient to alter postural sway. Hence, the findings of less frequent and more regular sway in patients with current LBP can be attributed to LBP.

The tendency toward a larger COP amplitude in patients with current LBP was in line with our hypothesis regarding the pain effect. Although this finding was not significant, a tendency toward increase of sway in LBP fits with findings from a recent systematic review,[2] which concluded that sway is likely increased in some patients with LBP but not all and that this may also depend on test conditions. LBP was also associated with increased COP regularity under increased balance demands, which is the narrow BOS especially when combined with the cognitive task. The lower SEn in the current-LBP group under high task demands found here is in line with previous findings of Sipko and Kuczynski.[20] This finding might reflect that more cognitive effort is invested in postural control as a result of LBP. The decreased frequency content of postural sway in the patients with current LBP might also reflect increased supraspinal control mediated by attention (Kiers H, van Dieen JH, Brumagne S, et al. Postural sway and integration of proprioceptive signals in subjects with LBP. Unpublished data.) Kiers *et al*, however, found an opposite effect of LBP on SEn when standing on foam, that is a more irregular

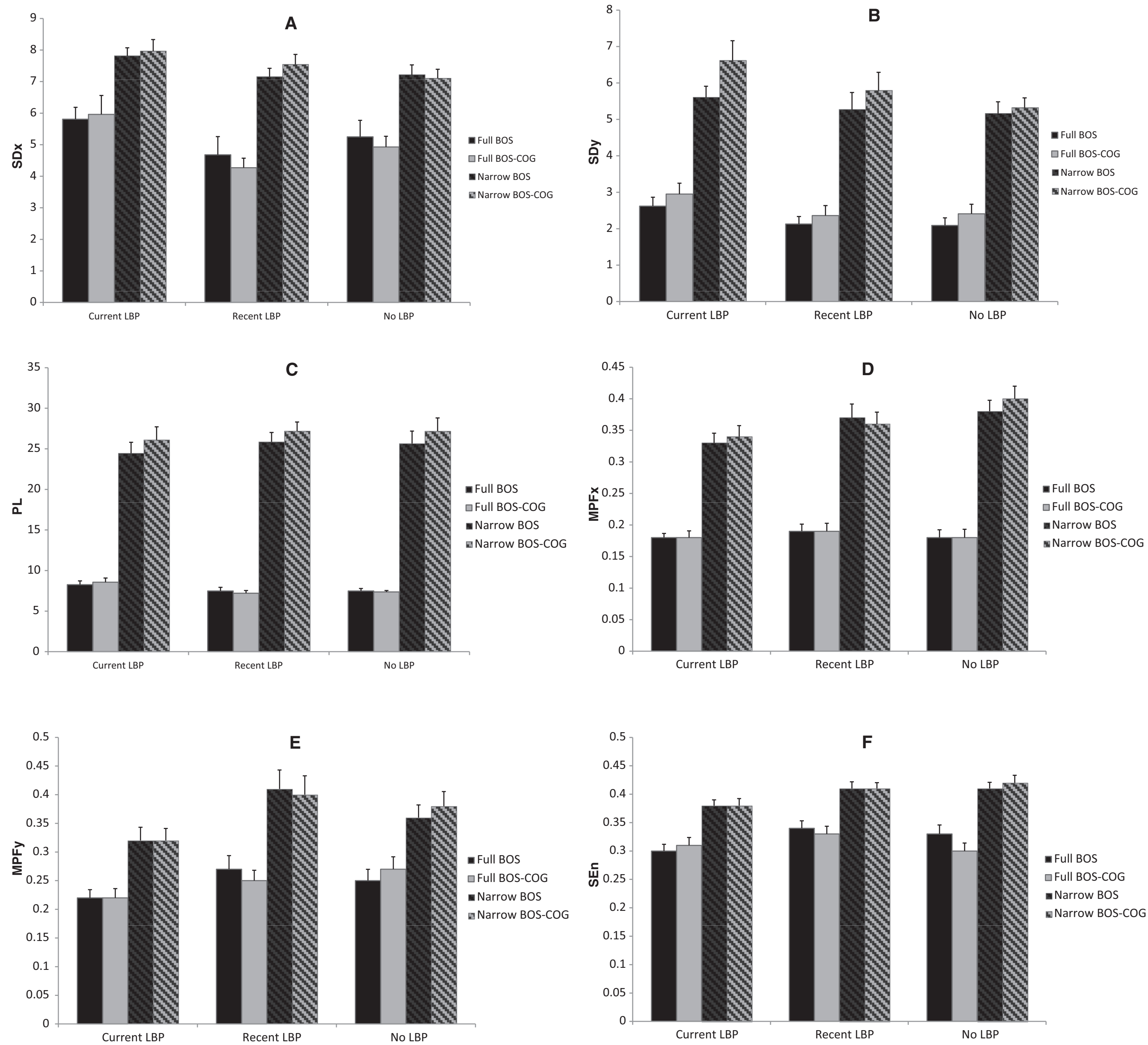

Figure 2. A–F, Plots representing body sway in different conditions of BOS and COG in current-LBP group, recent-LBP group, and no-LBP group for different postural variables: SD_x (**A**), SD_y (**B**), PL (**C**), MPF_x (**D**), MPF_y (**E**), and SEn (**F**). *x* and *y* represent anteroposterior and mediolateral directions, respectively. Error bars represent standard error of mean. SEn indicates sample entropy; BOS, base of support; PL, path length; SD_x, standard deviation of COP positions in AP direction; SD_y, standard deviation of COP positions in ML direction; MPF_x, power frequency in AP direction; MPF_y, mean power frequency in ML direction; COP, center of pressure; COG, cognitive loading.

and higher frequency sway was found in participants with LBP than in participants without LBP. This was interpreted as the effect of an increased stiffness through cocontraction, a strategy to rigidly control posture without requiring much cognitive effort. The difference between these findings might partly be explained by differences in the BOS conditions. Kiers *et al* used foam to increase task difficulty, whereas we used a narrow beam. Foam create a less relevant proprioceptive input on ankle angles and less input from foot sole receptors.[21] In addition, Kiers *et al* tested subjects with eyes closed. The testing conditions in their study thus caused an impoverished sensory input, which may have prohibited the use of a cognitively mediated feedback control strategy to increase control as a compensation for the disturbing effect of LBP. In contrast, standing on a narrow beam likely enhances sensory input from foot sole receptors and in addition it makes a cocontraction strategy less effective,[3] possibly a cognitively mediated strategy to enhance control was preferred in this condition. It should be noted here that, in apparent contrast with this explanation, Sipko and Kuczynski[20] did not find a main effect of standing on foam on sway entropy and even found an opposite effect in 1 group of participants in their study. Finally, case definition also differed substantially between these studies, but it is unclear how that would affect results.

Our findings also have clinical implications for rehabilitation of patients with nonspecific LBP. Because the changes of postural sway observed in LBP were mostly mediated by pain, pain control should be considered as a treatment component in the rehabilitation process to restore optimal postural control.

CONCLUSION

The results of this study indicate effects of pain on postural sway in patients with LBP and no effects mediated by FoP. Patients with current LBP showed lower sway frequency content in the ML direction and a more regular pattern of postural sway, especially when standing on a narrow BOS. These results suggest that more cognitive effort is invested in postural control in LBP, particularly with increased task demands.

➢ Key Points

- Postural sway of quiet stance was compared between people with current LBP, recent LBP, and no LBP in different conditions of support surface and cognitive loading.
- The current-LBP group reported significantly higher pain level, with FoP comparable between the current-LBP group and recent-LBP group.
- Patients with current LBP showed a postural sway with higher amplitude, lower frequency, and more regularity compared with other groups.
- More cognitive effort was invested in postural control in LBP, particularly under increased task demands.
- LBP effect on postural sway was mediated by pain rather than FoP.

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